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Adhesively bonded joints as a dissipative energy mechanism under impact loading

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ABSTRACT

The use of adhesives as a bonding system in aircraft construction has increased because of its structural efficiency, simplicity and lightness. New aircrafts are designed taking into account, among other criteria, security standards in case of crash or fall. For an aircraft, security techniques in case of collision can be defined as the internal system capability to prevent the passengers from being injured in an impact. A proactive proposal is to mitigate the impact energy absorbed by the passengers, by means of increasing as much as possible the capacity of the aircraft to capture energy. In this work, we suggest taking advantage of the energy that could be dissipated by the structural bonded joints due to their debonding process. We propose to optimise the geometry of the adhesive assembly in order to increase the amount of energy dissipated due to the damage of the adhesive during the crash. The scope is to define the best geometrical configuration of the joint to dissipate the largest amount of energy with safety purposes. To this aim, we study the behaviour of a bonded joint of two composites submitted to impact loading by means of the Finite Element Method.

1. Introduction

Polymer matrix composites based on fibre reinforcements are increasingly being used in aircraft structures because of their good structural performance: high strength, high stiffness and low density. Some of these structural components are assembled using adhesives and/or rivets. The use of epoxy-based adhesives in aircraft construction is an accepted joining method due to its advantages, such as simplicity, lightness and low cost.

The aerospace industry pursues appropriate techniques for improving human security in aircrafts. The design must consider all the possible sources of damage and alleviate them as far as possible. In case of fall or crash of an aircraft (or other vehicles such as cars or trains), one of the main causes of injury is the absorption of the impact energy by the occupants. Therefore, any mechanism that can dissipate even a small part of the impact energy is desirable for safety purposes. Military helicopters, like the USA UH-60 Black Hawk or the AH-64 Apache, were the first ones built following the modern specifications of security against collision [1]. The recently developed military and civil European helicopters, such as the NH-90, also take into account these security stipulations.

The present work is focused on the feasibility of increasing the percentage of energy dissipated by the aircraft structure during an impact (for example, the autorotation fall of a helicopter), without modifying the structure substantially. Hence,

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we propose to take advantage of the capability that an adhesive has for dissipating energy during its debonding process. During the damage process, the energy dissipated by the adhesive can be increased if the bonded joint develops all its failure modes as much as possible. Then, the idea is to determine the optimal geometry of the bonded joint that increases the dissipated energy in the adhesive. To this aim we have carried out a numerical study, by means of the Finite Element Method, to analyse the geometry influence on the behaviour of a bonded joint submitted to impact loading. Due to the general treatment of the problem, the results presented could be applied to the crash of different vehicles such as cars or trains.

The paper is organised as follows. In Section 2, the joint and the proposed geometry modification are described as well as the impact loading case studied. It is important to note that we do not study a real situation but a simplified one in which the joint has been isolated from the rest of the structure and impacts against a rigid surface. This section also includes details about the material models of the adherents and the adhesive based on damage mechanics. Under these conditions in Section 3 we investigate the influence of the joint geometry on the energy that can be dissipated by the adhesive and we present the results of the numerical study. As a first step, a single-lap joint is considered under static loading conditions. In this case the theoretical solution for the shear stress exists, so we use it to validate the adhesive model. Afterwards, we examine which is the maximum fracture energy that the adhesive could dissipate and which geometrical configuration of the joint leads to dissipate a higher percentage of the maximum fracture energy in the adhesive. It is also pointed out that more complicated models or different scenarios do not change the main results obtained. Finally, in Section 4 the conclusions are stated.

2. Description of the joint

2.1. Geometry

The joint considered is made up of two fibre-reinforced polymer skins (adherents) bonded together with a structural epoxy adhesive. Habitually this kind of joint appears in the secondary structure of some vehicles like helicopters (Fig. 1). The typical geometry considers that the bonded zone is in a horizontal position (Fig. 2(a)). The aim of this study is to revise if a certain inclination of the bonded zone increases the energy absorbed by the adhesive under vertical impact loading against a rigid surface. Therefore, we will consider the situation shown in Fig. 2(b), where the joint, the rigid surface and the impact's velocity v have been represented. The inclination angle of the joint θ is supposed to be variable. Then, we denote the thickness of the adherents and the adhesive as t and t_a, respectively, and the overlap length as l_a. Lastly, let us define the total length of the adherents as $L = l + l_a$ and the studied width of the joint as w.

2.2. Material models

The material behaviour for both, the adherents and the adhesive, have been modelled considering damage and failure mechanics. A failure mechanism consists of a first stage of an undamaged material response, and a second phase of damage evolution. The process of degradation begins when the stresses and/or strains satisfy a certain damage initiation criteria. Then, a damage evolution law describes the rate at which the material stiffness is degraded, losing the load-carrying capacity till the material fractures.

The damage models used in this work assume initially linear elastic behaviour and consider a linear softening law for the damage evolution. The constitutive equations are expressed in terms of stress-displacement relations, as shown in Fig. 3. The fracture energy can be defined as the total energy that is dissipated in the damage process. For each pure mode of failure, the fracture energy G^C is equal to the area under the damage curve (see Fig. 3). So that the energy dissipated during the damage process should be specified per unit area, not per unit volume.

Although this general framework is the same for the two materials considered, an epoxy for the adhesive and a fibre-reinforced polymer composite for the adherents, many aspects are defined differently. Therefore, the details of damage modelling for both responses are presented in the following section.

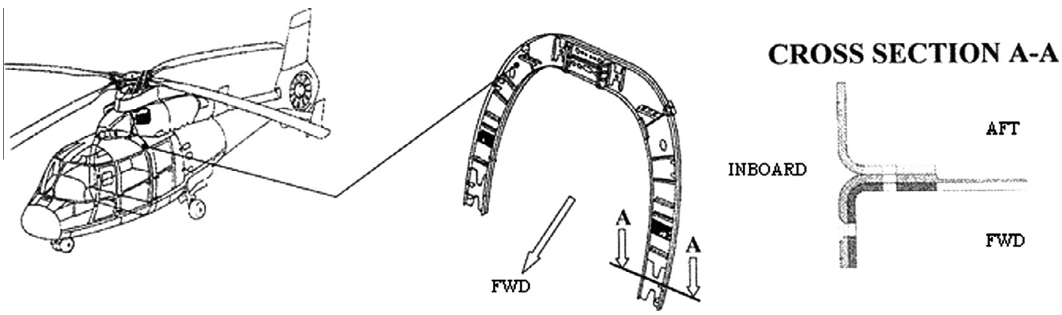

Fig. 1. View of the joint in its context: usually in the secondary structure of vehicles like helicopters (www.FederalRegister.gov).